CHAPTER III - TECHNICAL NOTES

1. VERIFICATION OF THE 48-HOUR FORECAST SECTOR OF 75 PERCENT PROBABILITY

a. INTRODUCTION:

At the 1971 CINCPAC Tropical Cyclone Conference the COMSEVENTHFLT Staff Meteorologist introduced an agenda item requesting that a statement of estimated error for the 48-hour outlook position be included in warnings issued by the Joint Typhoon Warning Center (JTWC). The Conference agreed that an estimated error was of value, however, it noted that no objective procedure had as yet been developed that could adequately depict what the estimated error would be for a particular forecast. The JTWC was therefore tasked to develop and test a means for estimating the error associated with a particular 48-hour outlook.

b. DEVELOPMENT AND TESTING:

During the 1971 tropical cyclone season, two methods of assigning confidence limits to 48-hour outlooks were developed and tested.

The first method consisted of constructing a segment of an annulus with the origin at the warning position and the segment centered about the 48-hour outlook position. The mean width was determined by striking a 240-mile arc (mean track error) centered at the 48-hour outlook position. The mean length was determined by moving 180 miles toward and away from the 48-hour outlook position. The 362 cases evaluated yielded a verification rate of 55%.

The second method used the 48-hour 50% climatology ellipse (obtained from the TYFOON analog computer program) as the confidence limit. Of 102 cases tested during 1971, 42% verified.

A combination of these two methods was then tested. This method consisted of a sector originating at the warning position, but limited by the larger of lines tangent to:

(1) The 50% climatological ellipse; or

(2) 120 miles across track and 180 miles along track from the 48-hour outlook position.

In no case would the resulting sector be smaller than either of the sectors derived using the first or second methods. Of the 94 cases tested using this third method, 79% verified.

Shortcomings were known to be inherent in all three of the methods tested. The first method failed in areas where climatological tracks diverge and in cases where recurvature occurred. The method based on the 50% climatological ellipse handled poorly those cases where there was a well-established westward track or climatologically unusual storms. The combination method demonstrated little skill when an abrupt course change occurred or during short-term accelerations or decelerations.

Although all three methods exhibited weaknesses, the combination method was chosen for operational use based upon its 79% verification during the 1971 test period.

c. UTILIZATION:

The 48-hour forecast sector of 75% probability was first issued on Typhoon Ora in June 1972.

The actual procedure used in its construction is depicted in Figure 3-1. First, the 48-hour 50% probability ellipse from the TYFOON analog program was plotted as shown in 1.a. Next, the forecast track was constructed. In 1.b. the forecast track and 48-hour outlook position lie within the 48-hour 50% TYFOON probability ellipse, although this is not a requirement. Third, using the 48-hour outlook position and track, 120-mile perpendiculars were drawn across track and 180-mile points were laid along track. Utilizing these points, tangents and arcs were drawn from

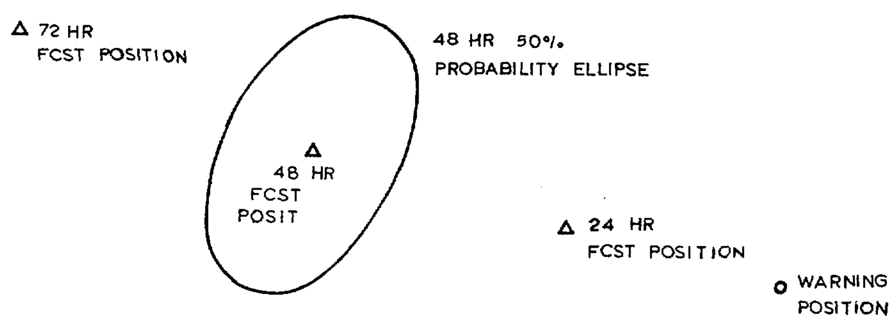

FIGURE 3-1.a. *Forecast positions based on TYFOON analog computer program.*

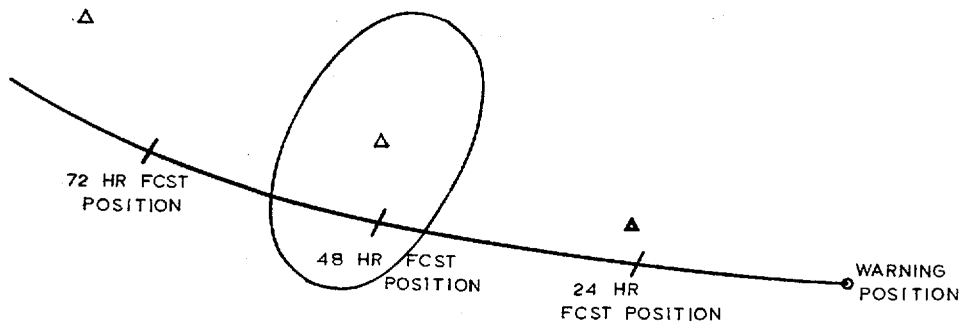

FIGURE 3-1.b. *Actual forecast track.*

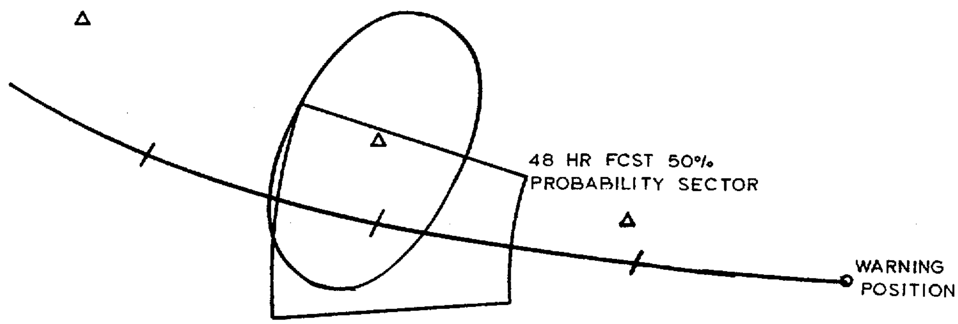

FIGURE 3-1.c. *48-hr forecast 50% probability sector centered on 48-hr forecast position.*

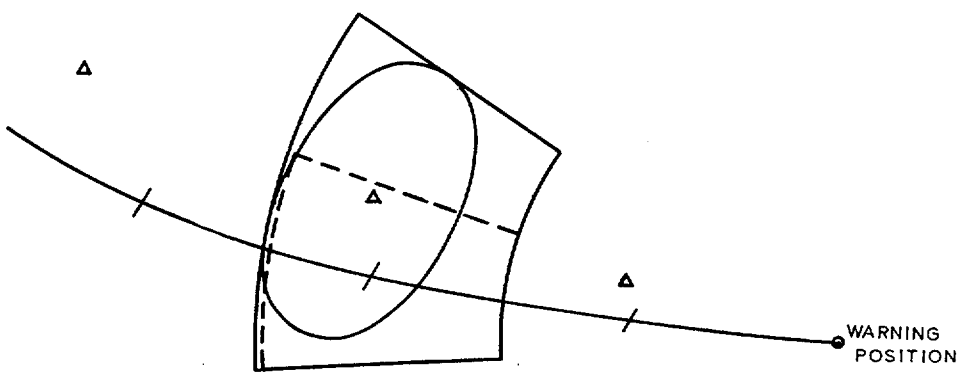

FIGURE 3-1.d. *The 48-hr forecast sector of 75% probability.*

the warning position, resulting in a wedge-shaped sector centered on the 48-hour outlook position as depicted in 1.c. Finally, taking the extreme positions of the 4x6 degree wedge-shaped sector and the 50% probability ellipse, tangents and arcs were drawn from the warning position resulting in the 48-hour forecast sector of 75% probability as shown in 1.d.

During the 1972 tropical cyclone season 48-hour 75% probability forecast sectors were included in 307 warnings. An individual storm and cumulative breakdown is provided in Table 3-1. As can be seen from Table 3-1, 27 of the forecasts were not verified. This was due to the tropical cyclone having dissipated or become extratropical by verification time. Of the 280 48-hour sector of 75% probability forecasts verified, only 153 or 54.6% of the actual 48-hour positions fell within the sector.

d. VERIFICATION PROCEDURES:

To determine if a bias existed in the method of constructing the sector, it was divided into four internal and four external parts for verification purposes as shown in Figure 3-2. All directions shown in Figure 3-2 and subsequent figures are relative to the storm tracks. The hypothesis on which the verification sector was based was that if no bias existed, then a

TABLE 3-1. INDIVIDUAL AND CUMULATIVE VERIFICATION STATISTICS FOR THE 48-HOUR FORECAST SECTOR OF 75% PROBABILITY

STORM NAME	INDIVIDUAL STORM FORECASTS ISSUED	INDIVIDUAL STORM WITHIN SECTOR	INDIVIDUAL STORM OUTSIDE SECTOR	INDIVIDUAL STORM NOT VERIFIED	CUMULATIVE TOTAL FORECASTS ISSUED	CUMULATIVE TOTAL WITHIN SECTOR	CUMULATIVE TOTAL OUTSIDE SECTOR	CUMULATIVE TOTAL NOT VERIFIED
ORA	9	4	3	2	9	4	3	2
PHYLLIS	33	4	24	5	42	8	27	7
RITA	50	23	27	0	92	31	54	7
SUSAN	1	0	1	0	93	31	55	7
TESS	25	11	10	4	118	42	65	11
ALICE	16	11	5	0	134	53	70	11
BETTY	24	20	4	0	158	73	74	11
CORA	10	6	1	3	168	79	75	14
ELSIE	4	1	3	0	172	80	78	14
FLOSSIE	11	9	2	0	183	89	80	14
GRACE	5	0	5	0	188	89	85	14
HELEN	7	3	2	2	195	92	87	16
IDA	18	12	3	3	213	104	90	19
KATHY	12	7	5	0	225	111	95	19
MARIE	18	11	4	3	243	122	99	22
NANCY	14	3	11	0	257	125	110	22
OLGA	16	9	4	3	273	134	114	25
PAMELA	12	6	4	2	285	140	118	27
RUBY	1	1	0	0	286	141	118	27
THERESE	21	12	9	0	307	153	127	27

normal distribution should be present both in and out of the sector.

Figure 3-3 shows the breakdown of the 280 forecasts verified. The distribution within the sector could be described as fairly normal. However, of the 127 forecasts that fell outside the sector, 59 or 46.5% were outside to the east of the storm tracks while only 15 or 11.8% were outside to the west of the storm tracks. Thus, the original hypothesis of no bias in the construction of the sectors was invalid.

Based upon the results contained in Figure 3-3, a new hypothesis was formulated, i.e., that a westerly bias existed in the construction of the sectors. To determine if this hypothesis was valid it was necessary to divide the storms for which 48-hour sector forecasts were issued into two categories:

(1) Northerly/recurving storms - those storms whose primary direction of movement was either to the right of 315°(T) or which recurved; and

(2) Westerly moving storms those storms whose primary direction of movement was to the left of 315°(T).

In making this division, the difference in the number of storms was quite small--11 classified as northerly/recurving and 9 classified as westerly moving. A major difference existed, however, in the number of sector forecasts issued--190 for northerly/recurving versus 90 for the westerly moving storms. This significant difference resulted from the climatologically disproportionate number of northerly moving systems experienced during the 1972 season that originated to the east of Guam where historical data was minimal.

If the new hypothesis of a westerly bias was correct, then the majority of cases verified for the northerly/recurving storms should fall to the right of the sector center. Similarly, for the westerly moving storms, the majority of cases should fall to the left of the sector center. Figures 3-4, northerly/recurving storms, and 3-5, westerly moving storms, confirm this hypothesis. In fact, a southwesterly bias was actually present, i.e.,:

(1) For northerly/recurving storms 63.7% of the predictions fell to the right of center and 55.8% fell above the center; and

(2) For westerly moving storms 60.6% of the forecasts fell to the left of center and 57.8% fell below the center.

Thus, the center of the average 48-hour forecast sector of 75% probability issued during 1972 was to the left and behind the actual average storm track.

e. RESULTS AND CONCLUSIONS:

A verification rate of only 54.6%, plus the presence of a southwesterly bias, indicated the need for a complete reanalysis of the procedures used in constructing the 48-hour forecast sector of 75% probability.

The southwesterly bias was attributed to two factors:

(1) The regression and correlation coefficients for TYFOON were recomputed after the 1971 season utilizing data from that year. The 1971 season had a preponderance of westerly moving storms. The result was a limited biasing of TYFOON toward westerly moving storms.

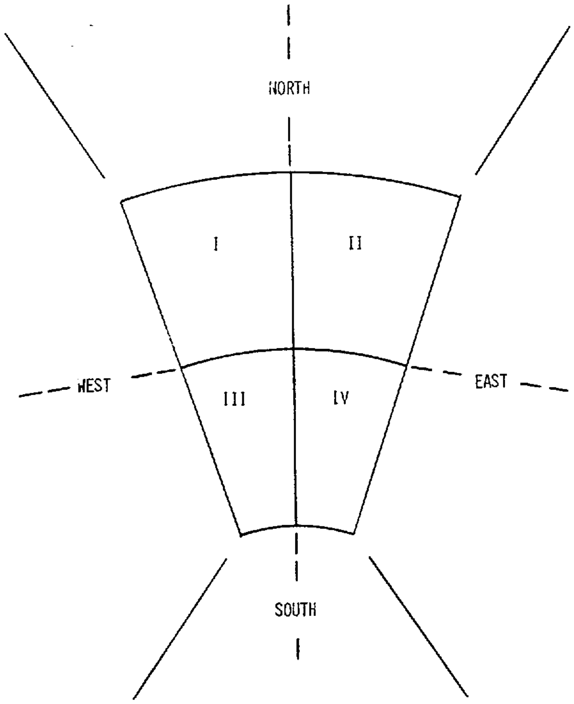

FIGURE 3-2. *Verification sector.*

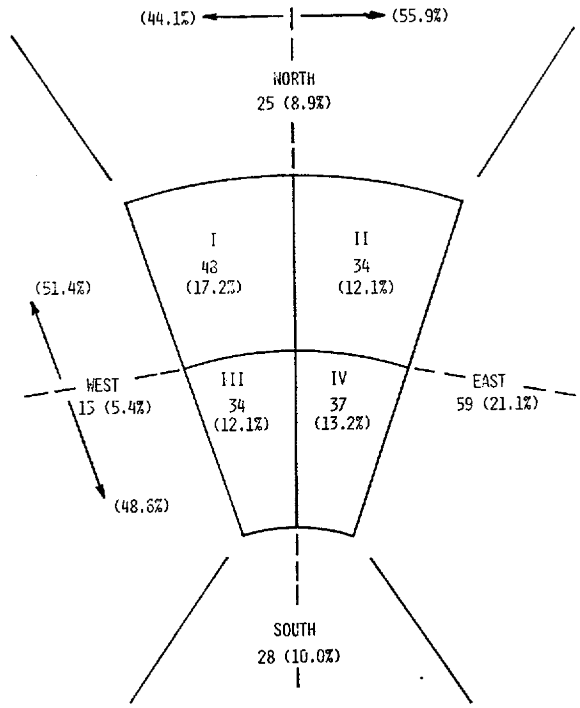

FIGURE 3-3. *Verification of sector forecasts issued during 1972.*

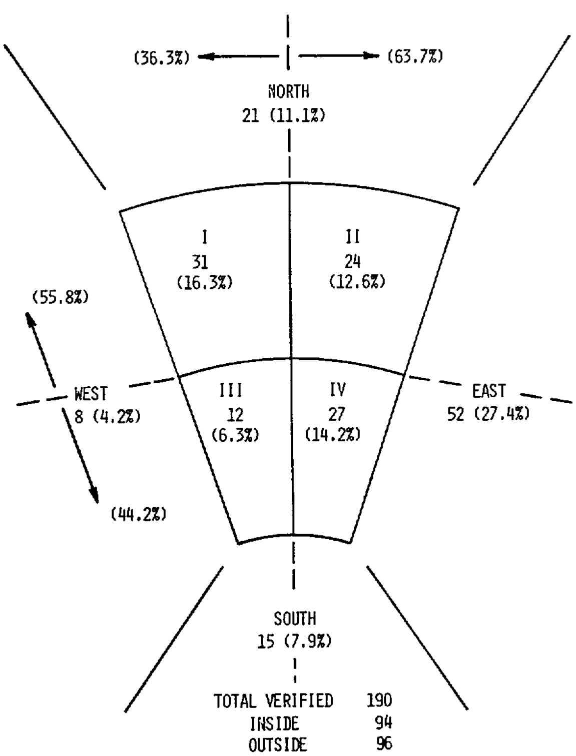

FIGURE 3-4. *Verification of sector forecasts for northerly/recurving tropical cyclones.*

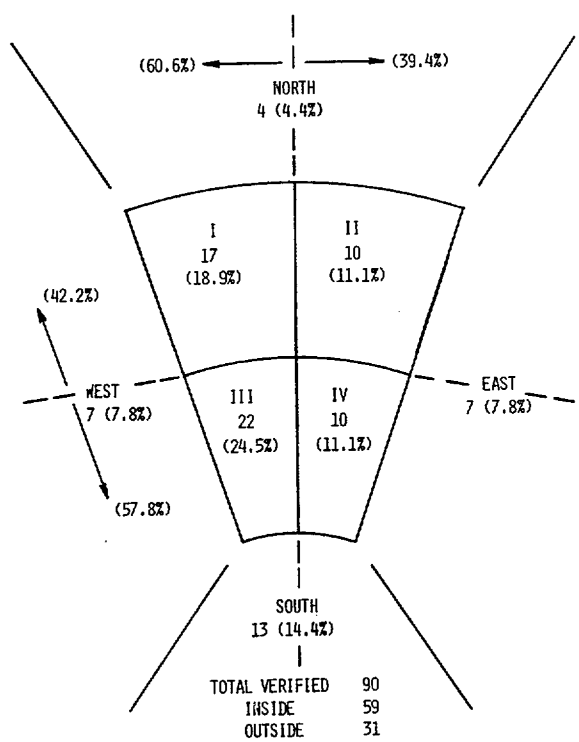

FIGURE 3-5. *Verification of sector forecasts for westerly moving tropical cyclones.*

(2) The JTWC has historically been slow to forecast recurvature by an average of one to two warnings.

These two factors contributed markedly to the center of the 48-hour forecast sector being to the left and behind the actual storm tracks.

When the sector was originally developed, it was assumed that the 48-hour 50% TYFOON ellipse and the 4x6 degree wedge-shaped sector were independent, thus establishing a 75% degree of confidence. Both subjective and mathematical investigation indicated that the original assumption was invalid. The 4x6 degree wedge-shaped sector was dependent upon the 48-hour outlook position and the forecast track. The forecast track, in turn, was derived from many inputs, one of which was the 50% TYFOON ellipses for 24, 48, and 72 hours. Therefore, true independence between the two did not exist. Utilizing this fact, it was mathematically determined that the optimum degree of confidence that could be expected using the present method would be about 65%. This equates with the actual verification statistics for westerly moving systems in 1972 of 65.5%.

During the 1972 season the average sector was approximately 270,000 nm^2. To insure that future sectors actually verified 75% of the time would require a minimum increase of 37% in the average sector size over the 1972 average. The result would be a sector of such dimension as to be of dubious value.

Although well received, on the average, by the users of Typhoon Warning WestPac, the 48-hour forecast sector of 75% probability has proven to be not only unreliable but even misleading. The JTWC sees no means of readily improving the present sector forecast system. An entirely new method must be developed and tested.

2. A RE-EVALUATION OF THREE-HOURLY FIXES

a. INTRODUCTION:

A JTWC presentation made to the 1972 CINCPAC Tropical Cyclone Conference contributed significantly to a recommendation for the deletion of mandatory 3-hourly fixes whenever a tropical cyclone was within 300 nm of a Department of Defense (DOD) installation. However, operational commanders retained the authority to request supplementary fixes if required for operational decisions or to safeguard DOD interests and lives.

The rationale behind the JTWC presentation in 1972, reproduced in the 1971 Annual Typhoon Report, was:

(1) Increased reconnaissance fixes would improve the accuracy of the warning position when based on interpolation but not extrapolation. Extrapolation would improve only until the distance between fixes became so small that inaccuracies in measurements were of the same order of magnitude as likely changes in the parameters measured; and

(2) The addition of 3-hourly fixes would increase the reconnaissance burden and be accompanied by a proportional increase in the missed-fix frequency.

The statistics presented, based on the evaluation of 1971 data, tended to support the rationale listed above.

b. RESULTS DURING 1972:

During the 1972 season the JTWC levied 78 3-hourly fixes, primarily in the South China Sea (SCS). These supplementary fixes were levied at the request of operational commanders, in anticipation of such requests, or to fulfill requirements for warnings.

Aircraft on two-fix sorties can get the intermediate fix as a bonus. Thus, during 1972, the 3-hourly fixes had a better miss/late rate than the overall statistics for the year as depicted in Table 3-2. This enabled the JTWC to obtain a more comprehensive evaluation of the tropical cyclone. More importantly, the average 24-hour forecast error for warnings based on consecutive 3-hourly fixes was less than for any other fix interval. A comparison of average 24-hour forecast errors for three separate fix interval categories and all warnings issued is shown in Table 3-3. This comparison shows that warnings based on two or more consecutive 3-hourly fixes are superior, on the average, to all other categories.

TABLE 3-2. THREE-HOURLY FIXES VERSUS SEASON'S AVERAGE

	THREE HOURLY FIXES	SEASON'S AVERAGE	SEASON'S AVERAGE LESS THREE-HOURLY FIXES
MISS RATE	11.5%	19.7%	20.7%
LATE RATE	7.7%	9.2%	9.4%
EARLY RATE	3.8%	1.9%	1.6%
MADE RATE	76.9%	69.2%	68.3%

TABLE 3-3. COMPARISON OF 1972 AVERAGE 24-HOUR FORECAST ERRORS

	AVERAGE 24-HOUR FORECAST ERROR
A. WARNINGS BASED ON:	
Consecutive three-hourly fixes	94 nm
Consecutive six-hourly fixes	111 nm
Missed aircraft recon fixes	134 nm
B. ALL WARNINGS ISSUED FOR:	
SCS tropical cyclones	105 nm
SCS tropical cyclones without three-hourly fixes	110 nm
All tropical cyclones	117 nm

c. CONCLUSIONS:

Although 1972 found a reversal in the results obtained in 1971, a two-year sampling of data is considered to be insufficient to arrive at valid conclusions. The majority of 3-hourly fixes in 1971 were levied as a system approached land. In 1972 most 3-hourly fixes were levied on cyclones moving over the SCS and undergoing reorganization and intensification. Also, tropical cyclones over the SCS are normally smaller than those in other parts of the western North Pacific.

In general, continuous 6-hourly fixes are sufficient for warning purposes only so long as the tropical cyclones are following a smooth path at nearly constant speed. However, for erratically moving or accelerating circulations, 3-hourly fixes are essential to the issuance of competent warnings.

3. AN AUTOMATED OBJECTIVE TECHNIQUE FOR CONSTRUCTING TROPICAL CYCLONE BEST TRACKS

a. INTRODUCTION:

The accuracy of tropical cyclone best tracks depends heavily on the techniques used in their construction (position/intensity histories). Due to changes in personnel, reconnaissance platforms, and procedures, these techniques have varied greatly over the years. Since reliable data are essential for progress in tropical cyclone research it is desirable that inconsistency be eliminated. It was with this goal that an objective analysis technique was developed.

b. GENERAL PROCEDURE:

The computer program takes cyclone fix information from punched cards, weighs and groups these data based on preassigned weighting factors and calculates latitude, longitude, intensity, and accuracy functions using linear and second order smoothing routines. The program incorporates both a position history routine to develop the actual storm track and an intensity history routine to derive the storm's maximum surface wind speed at each synoptic time.

(1) THE POSITION HISTORY ROUTINE - The program initially divides the time domain into 3-hourly intervals, or integral multiples of 3 hours, so that each interval contains at least one fix. To eliminate unwanted short-term movements, a group point is derived from a weighted combination of the fixes contained in each time interval. This group point is assigned a time, position, and accuracy values, all weighted by the accuracies of the fixes used to produce the group point. The set of group points then undergoes four linear smoothing/accuracy adjustments where each group point is adjusted in relation to adjacent group points. After linear smoothing, five group points at a time (i, $i + 1$, $i + 2$, $i + 3$, and $i + 4$) are considered in a second order smoothing routine. During this process, points $i + 1$ and $i + 3$ are adjusted in reference to a second order polynomial drawn through points i, $i + 2$, and $i + 4$. After completion of two second order smoothings, the position history, as defined by the collection of group points, is adjusted to correct any corner cutting that may have been introduced during the smoothing cycles. The program then calculates latitude, longitude, and position accuracy values corresponding to the set of desired best track times using second order interpolation.

(2) THE INTENSITY HISTORY ROUTINE - This portion of the program closely parallels the position history routine. Differences exist in that, unlike position information, much of the intensity information cannot be read directly from fix data cards but must be constructed from other measured parameters. In addition, some fixes lack intensity estimates altogether. In these cases intensity data from neighboring group points are used.

c. FUTURE DEVELOPMENT:

All fixes used in the procedure are assigned an accuracy weighting factor which determines how much influence they will have on the final best track positions of the storm. The merit of an objective best track routine depends on the goodness of the weighting factors used. The factors are assigned based on the probable errors of the fix method utilized and modified if better information as to the accuracy of the fix is available. The values assigned to various fix methods are based on limited data and will be refined as the data base enlarges. Results gained in testing the program with 1972 data are very encouraging, indicating that the objective best track program represents a significant advance in post-seasonal tropical cyclone track analysis.